91602,
new 82-10

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

TO: MR. J.E. MITCHELL
Manager
Technical Services & Development Department
Program Services & Development Division
C25F6

Energy Monitoring of a Ground-Source Heat Pump System at Janet Lee Public School, Stoney Creek, Ontario

F.J. Lenarduzzi, D.L. Vellekoop

Abstract

The heating, ventilating and air-conditioning (HVAC) system for a modern school in Ontario must satisfy a number of competing demands. On one hand, school boards are looking for highly energy-efficient designs. On the other, the Ministry of Education has increased the minimum standards for fresh air supply in new schools, thus increasing the heating costs. The HVAC designer is faced with the task of supplying and conditioning fresh air while consuming a minimum amount of energy in the process. Ground-source heat pumps offer an opportunity to cut operating costs while providing a comfortable working and learning environment. At the Janet Lee School, energy savings have been achieved without compromising the building comfort. Energy savings in the order of 60% over electric resistance heating have been measured.

Introduction

The Janet Lee Public School in Stoney Creek is the first elementary school in Ontario to utilize ground source heat pumps for space conditioning. When it opened in September 1987, the Utilization Section began a detailed monitoring program to determine the potential energy savings offered by this application of ground source heat pump technology to a modern school design.

Based on energy data that has been acquired for one complete year the school has reduced the space heating energy costs by over 60% compared to electric resistance heat. A summary of the information pertinent to the energy consumption of the school is given in Table 1.

job	file	date	report no.
12-187	814.3	June 20, 1990	90-62-K

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Building Description

The building is a square layout single storey structure of typical new school construction; poured slab floor on grade, cavity block walls with 2" rigid foam insulation, brick veneer, and a tar and gravel roof built up on 3" rigid insulation. The windows are double glazed and operable. The school has 13 classrooms, 2 kindergarten rooms, a general purpose room, library and administrative offices. The total floor area is 3250 m^2 (35000 ft^2).

Heat Pump System

Buried under the playing field is 7320 m (24000 ft) of plastic pipe. This pipe is divided into four loops each containing 1830 m (6000 ft) of 30 mm (1 1/4") polyethylene pipe. Each of the four major loops is buried in a series of nine trenches approximately 1.8 m (4 ft) deep. Four pipes are arrayed in each trench as shown in Figure 1. These collectors are connected in parallel to 50 mm (2") headers which also connect 14 heat pumps located in the mechanical room of the school. Each heat pump produces 12 kW of heat (~4 tons) to the supply headers which feed the school.

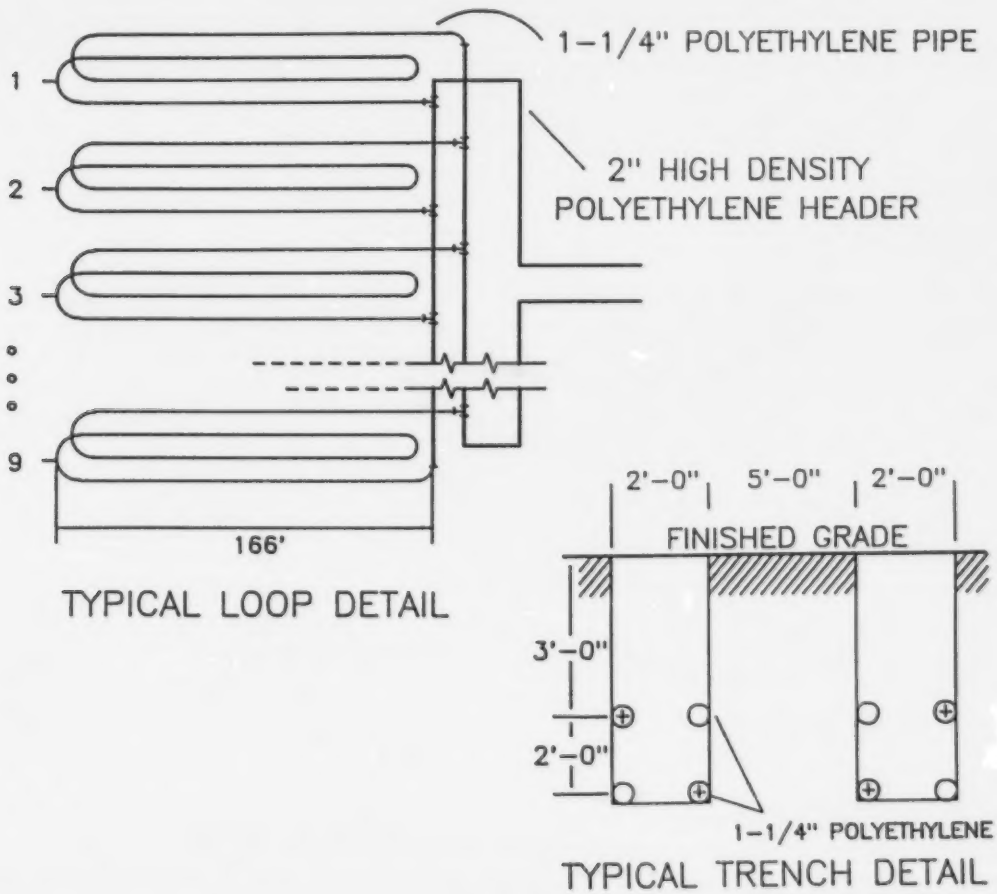


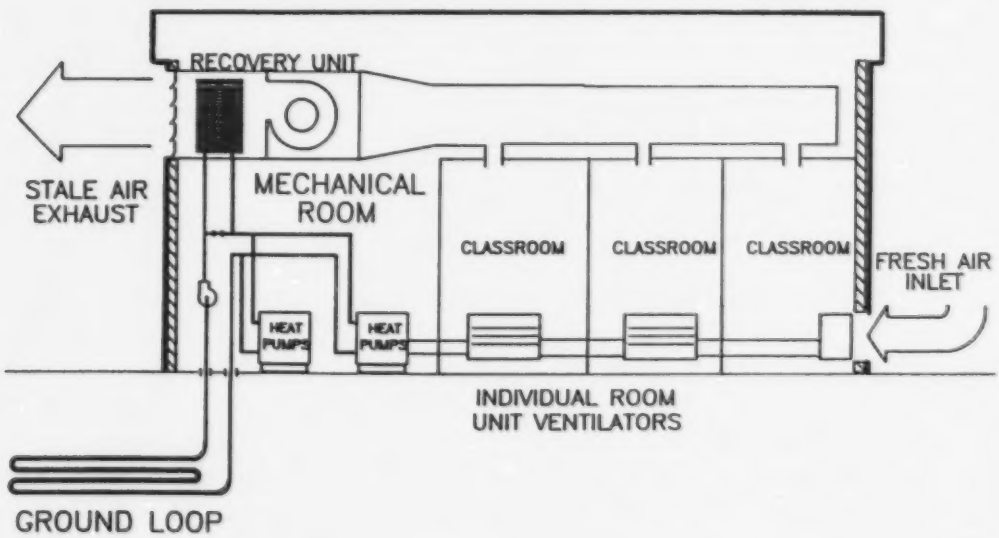
Figure 1

The school is physically divided into four space-conditioning zones. The heat pumps are also divided into four groups, each of which supplies hot or cold water (as the season demands) to all the rooms in a particular zone. Each room is equipped with a unit ventilator which draws in fresh air from outside, mixes it with recirculating air from the classroom, and heats or cools by passing it across a finned-tube coil fed by the heat pump circuit. A fifth "zone" consisting of two 7 kW (2 ton) heat pumps supplies domestic hot water to a recirculating loop.

Air is removed from each room in the school by a duct network common to the whole building. This return duct terminates in the mechanical room. Here, the exhaust air is drawn through a heat recovery unit which transfers some of the heat to the ground loop. The exhaust-air blower has a variable speed drive to maintain a slightly negative pressure in the school and facilitate fresh air infiltration through the unit ventilators. Figure 2 below illustrates the components of the entire system as they are connected in the school.

Control Description

The hot water supply temperature for each of the four zones is controlled by a programmable controller which operates the heat pumps by staging them on and off in pairs as required to maintain a preset supply water temperature in each zone. If the heat pumps are unable to maintain the zone water temperature, a separately-controlled electric immersion heater can be energized manually. The school's space temperatures and ventilation rates for each room are controlled according to a preprogrammed schedule of occupancy data by a Johnson Control DSC 8500 microprocessor. The operation and interaction of these controls was considered beyond the scope of the current study.



MAJOR COMPONENTS OF HEATING/VENTILATION SYSTEM
JANET LEE SCHOOL STONEY CREEK

Figure 2

Monitoring Hardware Description

Ontario Hydro monitored the energy consumption of the school in order to measure the savings in demand over a conventional electric-resistance school. An 8-channel RIM recorder was installed to measure the electrical consumption of the school and various components of the heating system, the ground loop temperature, and the outdoor temperature.

The electrical consumption of the fourteen heat pumps was measured by four channels of the RIM recorder. Each channel measures the heat pumps grouped in one of the four zones. As a further check on the accuracy of this measurement, spot readings of the power consumption were taken using a portable power meter.

To determine the performance of the heat pump system, an integrating heat flow meter was installed on each of the four water supply loops. Each meter consisted of an inline flow meter, two temperature probes, and an integrating totalizer. The energy readings were recorded daily by the maintenance staff, enabling a daily calculation of COP. During monthly site visits the water loop supply and return temperatures were taken with thermocouples and thermometers to confirm the measurements recorded by the heat flow meters.

The electrical consumption of the domestic hot water heat pumps was measured on a spot basis, and elapsed time and cycle counters were used to record the operating times for these heat pumps.

Observations

Table 1 below lists the school energy consumption measured by the utility power meter and summarized as monthly values. In the first full calendar year of operation, the school used 453 MWh of electrical energy. This works out to 139 kWh/m^2/year or 12.9 kWh/ft^2/year in annual energy consumption, which is about 30% higher than predicted by the mechanical consultant. The table also provides estimates of the cost and energy required to supply the same school using an electric-resistance boiler. The data shows that the demand was reduced by approximately 80 kW, and energy costs were reduced by $13,700 in 1988 using the ground source heat pump system.

The electrical consumption of the back-up heating system was to be measured by a channel on the RIM recorder, but back-up heating was never operational in 1988. Even though there was a need for the back-up heating during cold weather, the heaters did not operate due to control equipment problems. To reduce the heat required during these time periods, the ventilation air was reduced.

The thermal outputs of the four heat pump zones were recorded by the heat flow meters previously described. From the ratio of thermal output to electric input for each zone, COPs were determined for individual zones. Further, by adding the thermal output to the school's non-heating electric load, an accurate prediction of the electric demand was plotted for an equivalent school with electric resistance heat.

Figure 3 depicts the daily loads for part of the period covered by Table 1. Figures 4 and 5 show the hourly electric demand for the heat pump system and total school, plus the calculated hourly profiles if electric resistance heaters were used instead of the earth energy system. Two months are highlighted; October, a typical month of mild weather and low electrical demand, and February, typifying severe weather conditions and the resultant higher electrical demand.

TABLE 1

1988 ENERGY DATA SUMMARY
JANET LEE SCHOOL STONEY CREEK

MONTH	PEAK HOURLY DEMAND kW	SCHOOL TOTAL ENERGY kWh	COST $	HEAT PUMP SYSTEM ENERGY kWh	THERMAL LOAD HTG ONLY kWh	ESTIMATED VALUES IF BUILDING USED ELECTRIC BOILER		
						PEAK kW	TOTAL kWh	COST $
JAN	166	56230	2803	26766	67307	246	96861	4657
FEB	154	52800	2622	25172	62922	228	90550	4346
MAR	141	48640	2412	23287	57739	209	83092	3988
APR	134	43840	2203	22692	59978	199	81126	3874
MAY	128	34240	1815	17978	46120	190	62382	3128
JUN	134	31680	1742	N/A	N/A	134	31680	1742
JUL	141	21680	1391	N/A	N/A	141	21680	1391
AUG	96	14760	950	N/A	N/A	96	14760	950
SEP	134	28160	1608	14993	37343	200	50510	2717
OCT	147	34240	1890	17978	46120	218	62382	3239
NOV	141	41280	2133	21435	56282	209	76127	3724
DEC	147	45560	2319	21892	53902	218	77570	3814
TOTAL		453200	23888	192193	487713		748720	37569

Figure 3a compares the heat pump system electrical energy and the thermal output energy produced for two months: October, a mild month, and February, a cold month. Included in the heat pump system electrical consumption is the energy consumed by the fourteen heat pumps and about 80 kWh per day consumed by the ground loop circulating pump. The thermal output energy is the energy produced by the four heat pump groups as measured by the four energy meters. Note the demand reduction increases dramatically as the thermal demand increases.

Figure 3b compares the daily total school electrical consumption with the estimated consumption of the same school using an electric-resistance boiler. From this graph, the energy savings can be compared with the actual daily energy use.

Figure 4 illustrates hourly demand profiles for a typical weekday and weekend day in February. The graphs for Sunday show that the operation of the heat pump system represents a steady flat demand. The Wednesday graphs indicate that the peak daily demand is caused by lighting, ventilation and other building loads superimposed on the heat pump demand. In all four graphs, the demand savings of the heat pump system over the (simulated) electric-resistance boiler are the differences between the top and bottom lines.

Figure 5 is similar to Figure 4 but for the month of October. The hour-by-hour demand for typical weekdays and weekend days shows a lower demand for the mild weather period. Again, the weekend data illustrates a flat demand compared with the week day. The week day data also illustrates the demand reduction as the difference between the heat pump system and the simulated electric-resistance boiler.

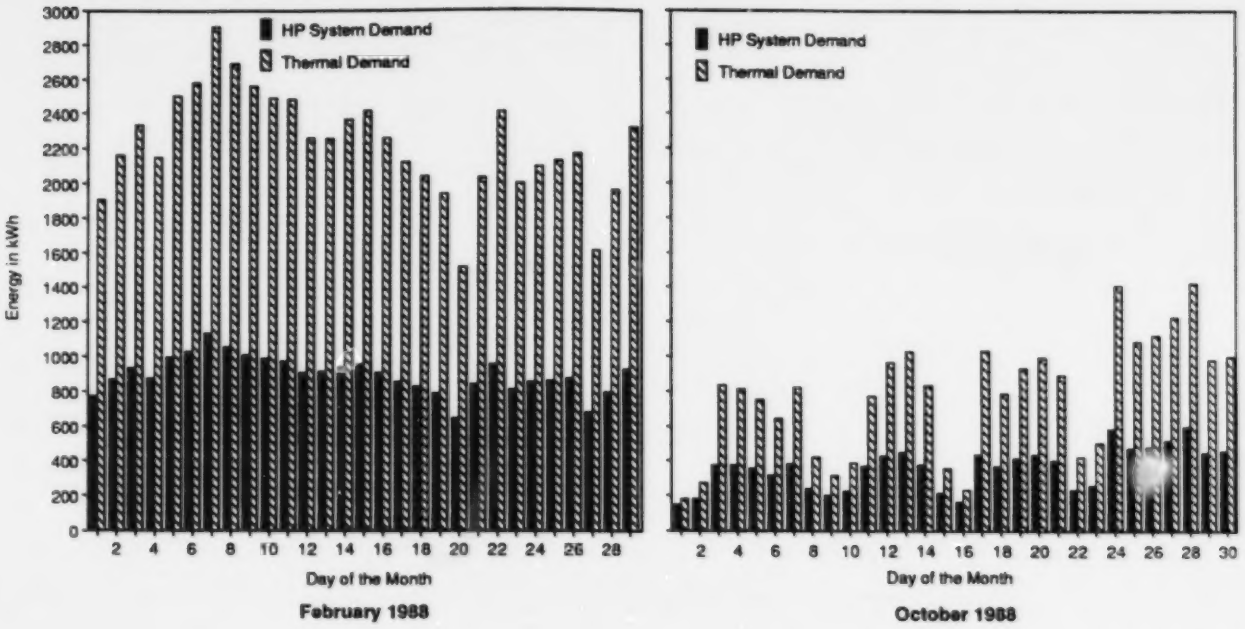


FIGURE 3a

HEAT PUMP HEATING SYSTEM DAILY ENERGY USE

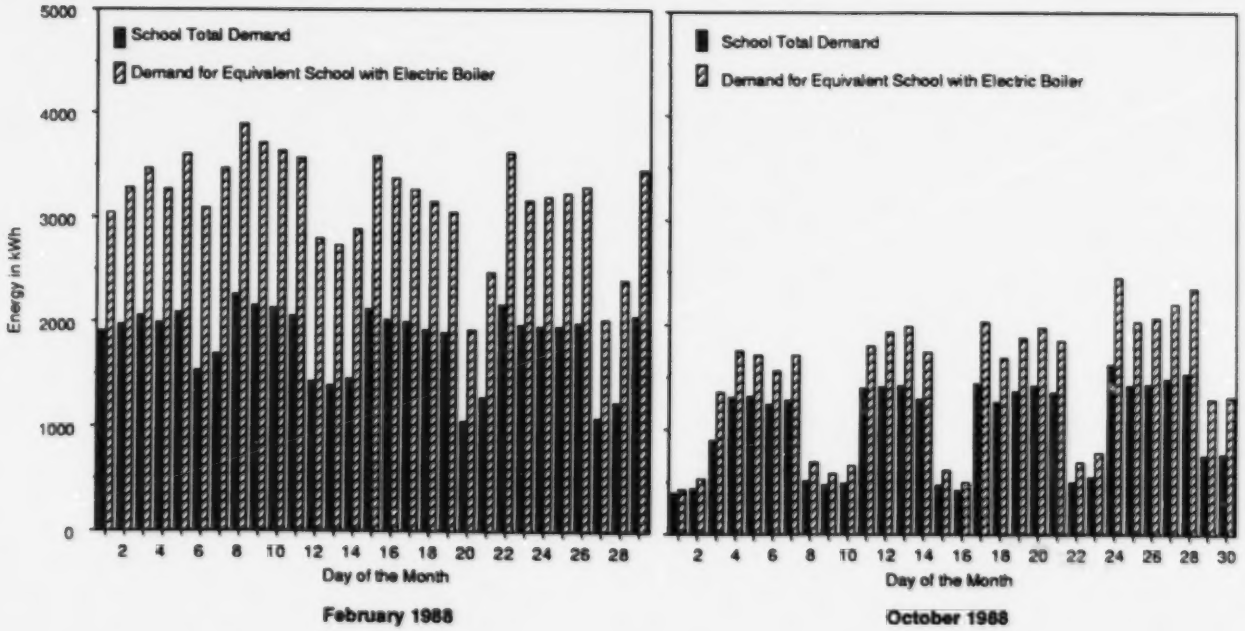
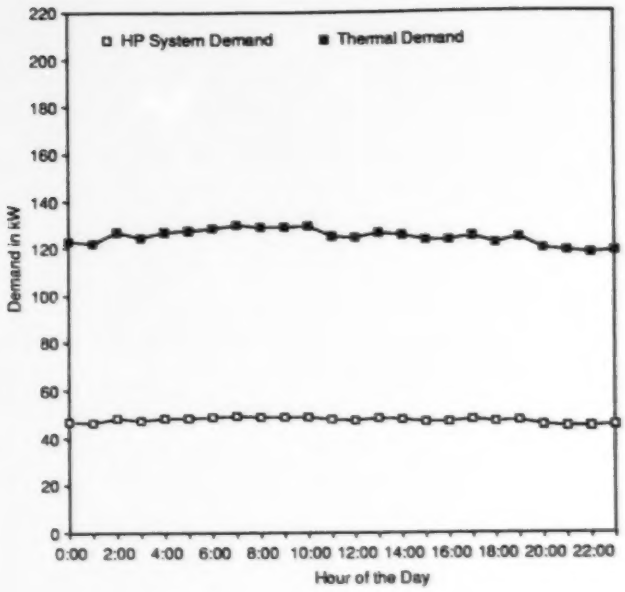
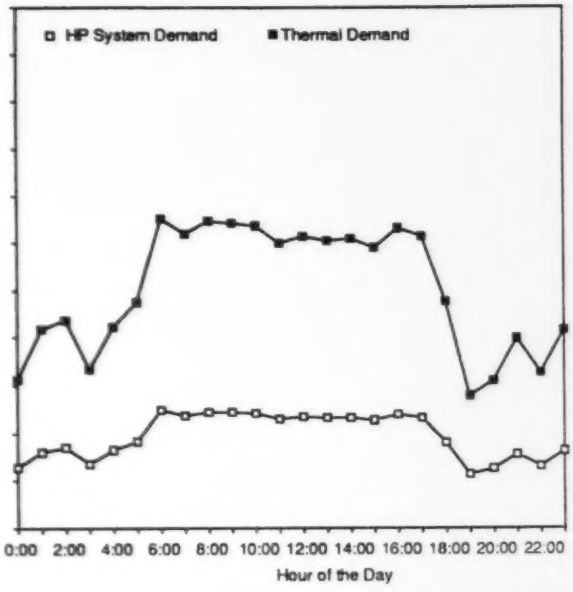


FIGURE 3b

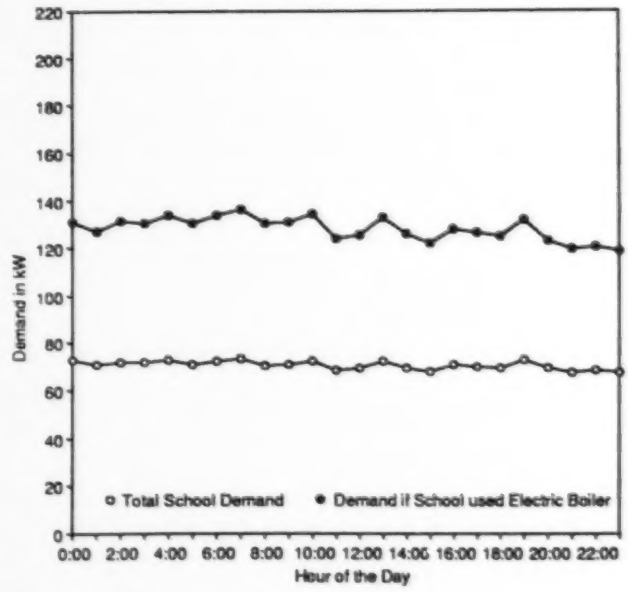
TOTAL DAILY ENERGY USE AT JANET LEE SCHOOL



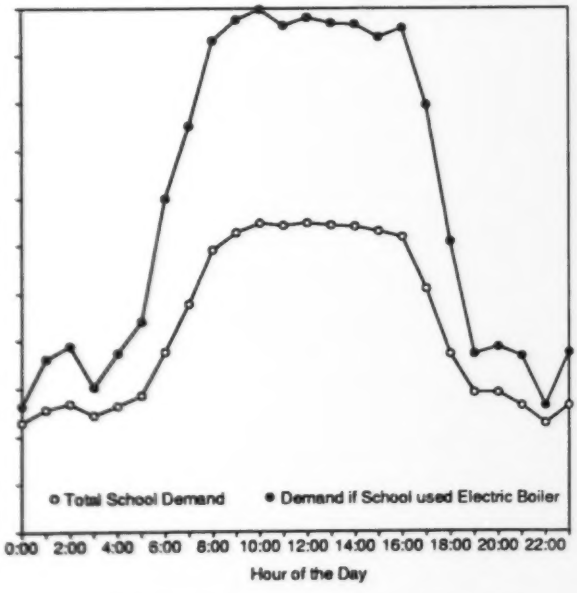
HP System Demand for Sunday February 7, 1988



HP System Demand for Wednesday February 3, 1988



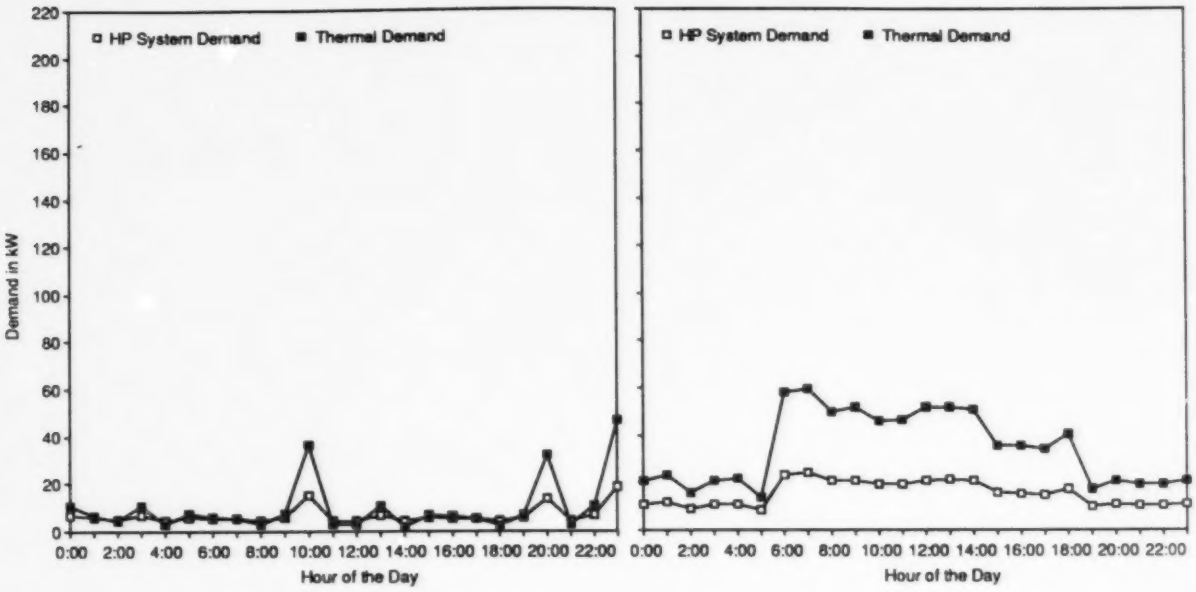
Total Bldg Demand for Sunday February 7, 1988



Total Bldg Demand for Wednesday February 3, 1988

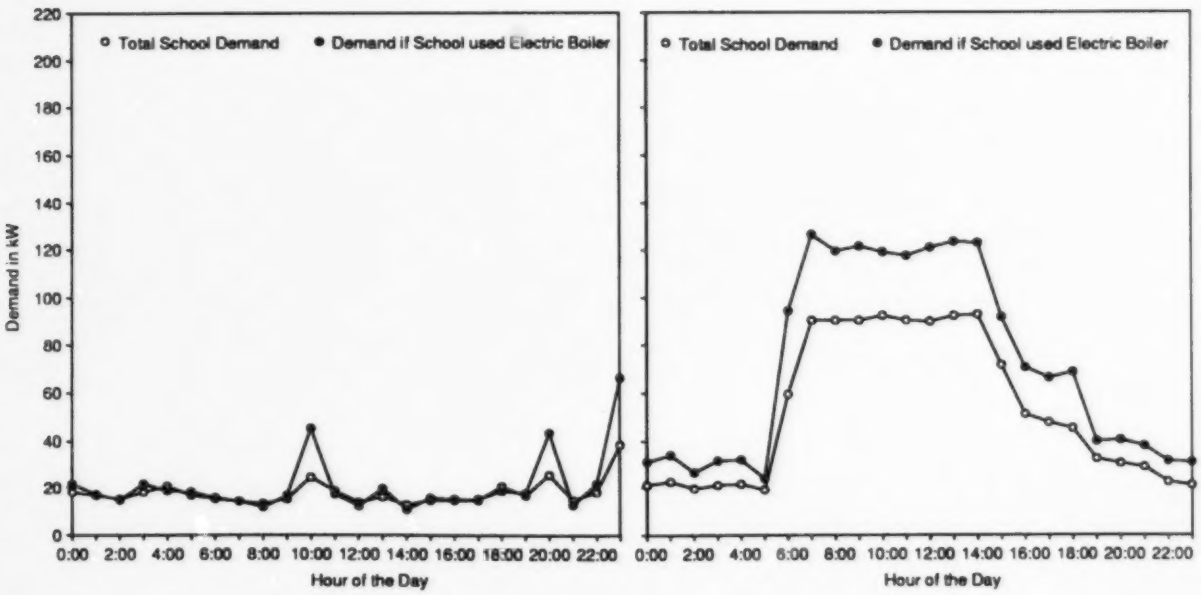
FIGURE 4

TYPICAL COLD WEATHER HOURLY ENERGY CONSUMPTION



HP System Demand for Sunday October 16, 1988

HP System Demand for Tuesday October 18, 1988


Total School Demand
Demand if School used Electric Boiler
Demand in kW
Hour of the Day
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00

Total Bldg Demand for Sunday October 16, 1988

Total Bldg Demand for Tuesday October 18, 1988

FIGURE 5

TYPICAL MILD WEATHER HOURLY ENERGY CONSUMPTION

Figure 6 compares hourly demands for the heat-pump-equipped school with the estimated demand of an electric-resistance-boiler-equipped school for December 12, 1988. This was the Ontario Hydro peak demand day for 1988. At the school peak (11:00 AM), the demand reduction was 80 kW compared with an electric boiler. The difference between the electric input and thermal output lines for the heat pump is termed "Free heat", which is exactly equal to the heat absorbed by the ground coil. At Hydro's peak (5:00 PM) the demand reduction was 50 kW. Note in Figure 6b that the demand curve is flat between 00:00 h and 14:00 h indicating that the system is operating at full capacity.

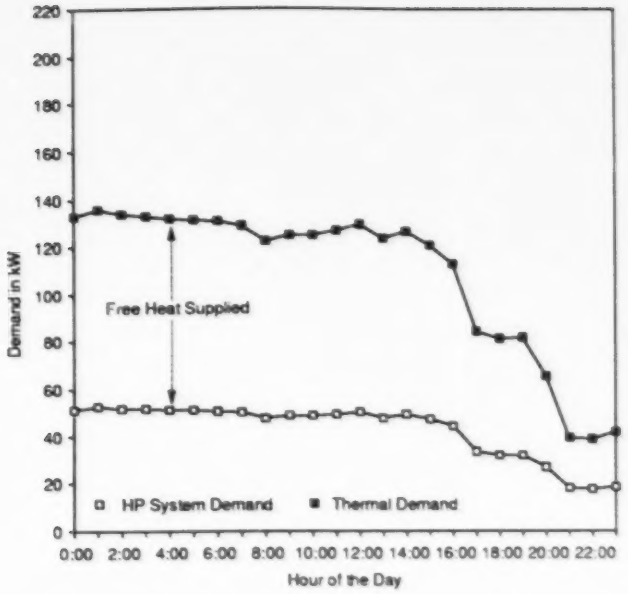
The ground loop return temperature was measured on the RIMS recorder for the entire year. This measurement was verified from time to time using a thermometer in the return header. Figure 7 illustrates the average, maximum and minimum daily ground temperatures for the month of February. The temperatures are about 2°C colder than expected for this type of ground loop at this time of year. The ground loop is about 30% shorter than specified by conventional design practise, but it was expected that the makeup energy supplied by the exhaust-air heat recovery unit would supply the difference. However, during the monitoring period, the exhaust-air heat recovery unit was not operated in cold weather. The result was a drop in ground loop temperature. The exhaust-air heat recovery system has only operated intermittently during the monitoring period. The supply valve to the air-to-glycol heat exchanger was inoperative until the beginning of 1988. When the unit did operate, particularly in cold weather, too much fresh air would enter the school. Without back-up heaters, (not available due to control problems) the heat pumps alone could not maintain the supply water temperature. As a result, classroom temperatures would fall, so the exhaust ventilator would have to be shut down manually.

Figure 8 illustrates the temperatures measured with the exhaust-air recovery unit running. Without the heat recovery unit operating, ground temperatures are lower than expected, but the building heat loss is also lower because the fresh air infiltration is drastically reduced. It is not known what effect this has on the overall efficiency of the system. The building is probably using less energy than it would if everything was working, since the ventilation rate is reduced. However, the heat pumps are operating at lower efficiencies because the heat recovery unit does not boost the loop temperature. Until the back-up heaters become available, system efficiency under normal operating conditions cannot be measured at the intended design specifications.

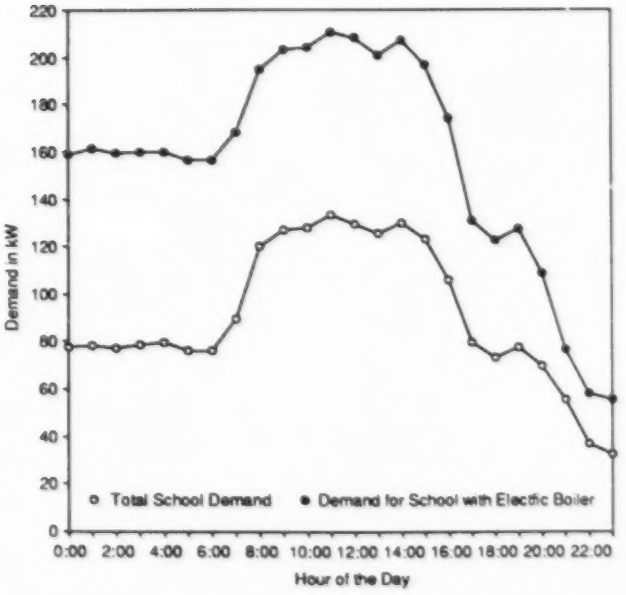
Hot Water Load

It was not possible to determine total hot water consumption for the school. The two heat pumps which heat the domestic hot water supply only half of the hot water demand. The rest of the school is supplied by conventional electric water heaters distributed throughout the building. The demand for hot water is low. The only shower in the building has never been used. Hand washing and art room cleanup seem to be the major loads.

Elapsed time meters and cycle counters were used to determine the electrical consumption of the domestic hot water heat pumps. The system consists of 2 circulating pumps which run continuously, and 2 heat pumps which operate for an average of 1.2 hours daily. The system consumes an average of 22.3 kWh/day, of which 19.2 kWh is used by the circulating pumps. This represents an average of less than 2% of the total electric consumption of the school. Because the system supplies only half of the domestic hot water, few conclusions can be drawn about costs or savings associated with this application. However, the low daily operating hours (1.2 h) indicate that the system is poorly utilized.



HP System Performance for December 12, 1988



Total School Consumption for December 12, 1988

FIGURE 6

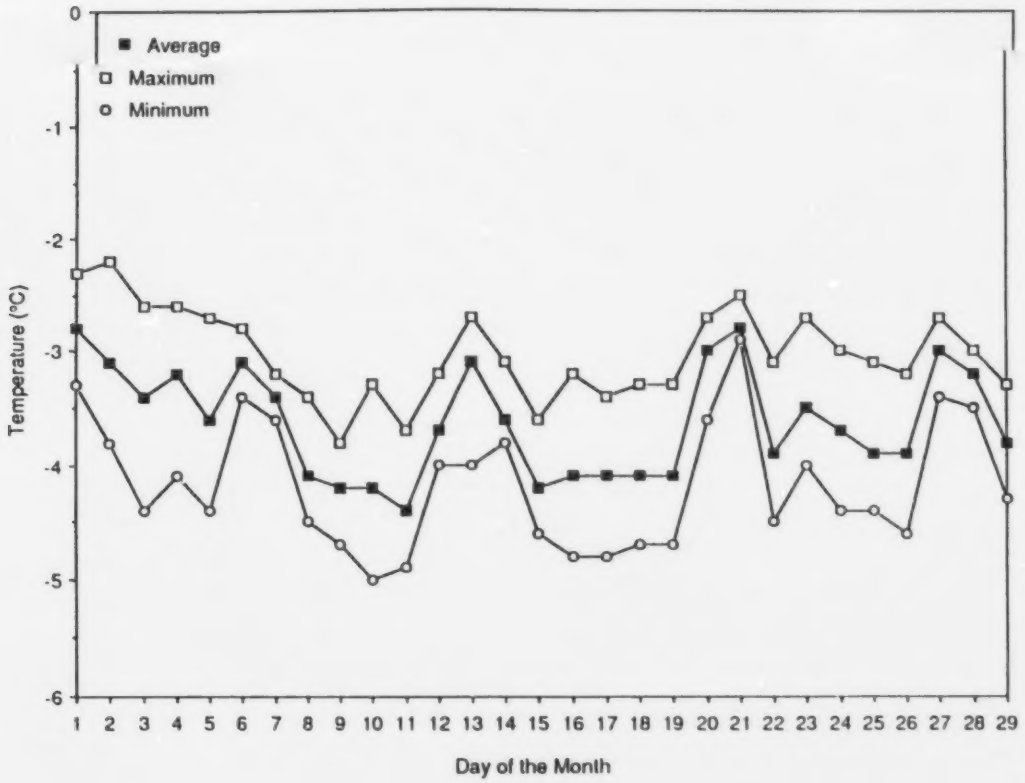
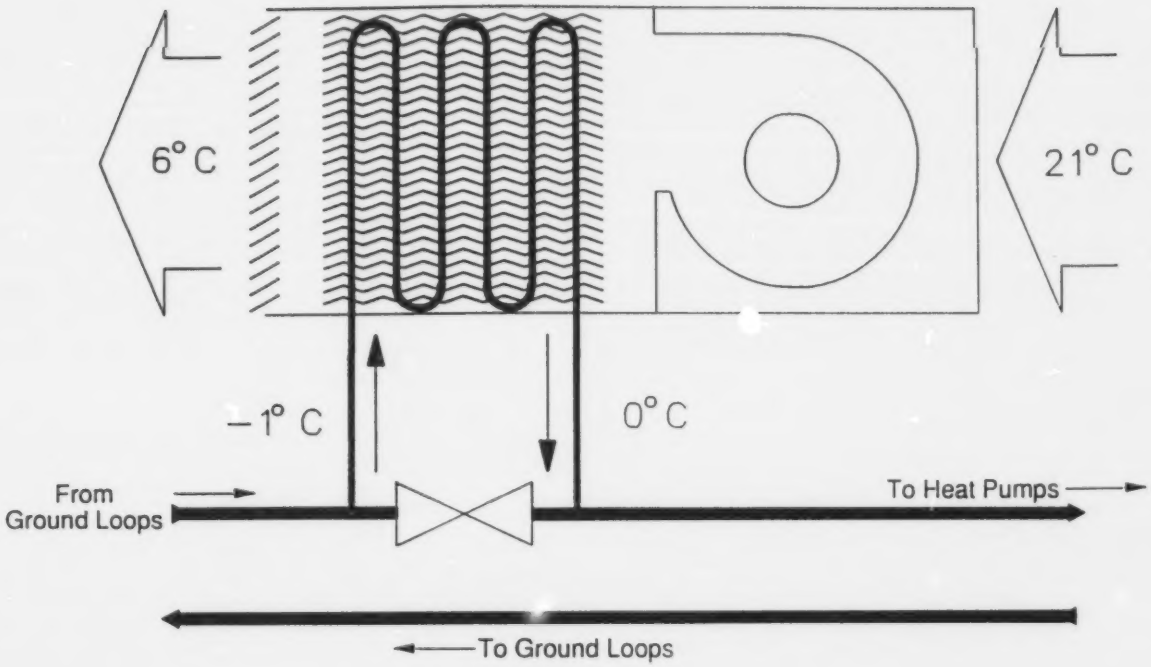


FIGURE 7

DAILY GROUND LOOP RETURN TEMPERATURE

Discussion

The use of a ground source heat pump system has resulted in savings of energy for the school. The Wentworth County School Board, which owns the school, reports large savings compared with an electrically-heated school of similar size and construction. Our data shows peak savings of 80 kW over a conventional electric boiler. However, the system suffers from deficiencies which have not yet been corrected and which probably result in a reduced efficiency in the operation of the system. To a large degree, these deficiencies are due to the design, commissioning and operation of the ventilation components of the school, and are not due to the ground loop or heat pumps which have functioned problem-free since the fall of 1987.



EXHAUST AIR RECOVERY UNIT

Figure 8

In general, Research Division energy monitoring experiments should not begin until a full year after the completion of the building, if normal operating data is to be obtained. Otherwise, Research personnel may be obliged to become involved in trouble-shooting and commissioning activities, to the detriment of the monitoring project's budgets and schedules.

With respect to the design of the ventilation system, two items should be noted for any future schools designed with a similar concept. The first is the selection and operation of the unit ventilators which supply and condition classrooms with fresh air. The second is the return duct layout in the classroom.

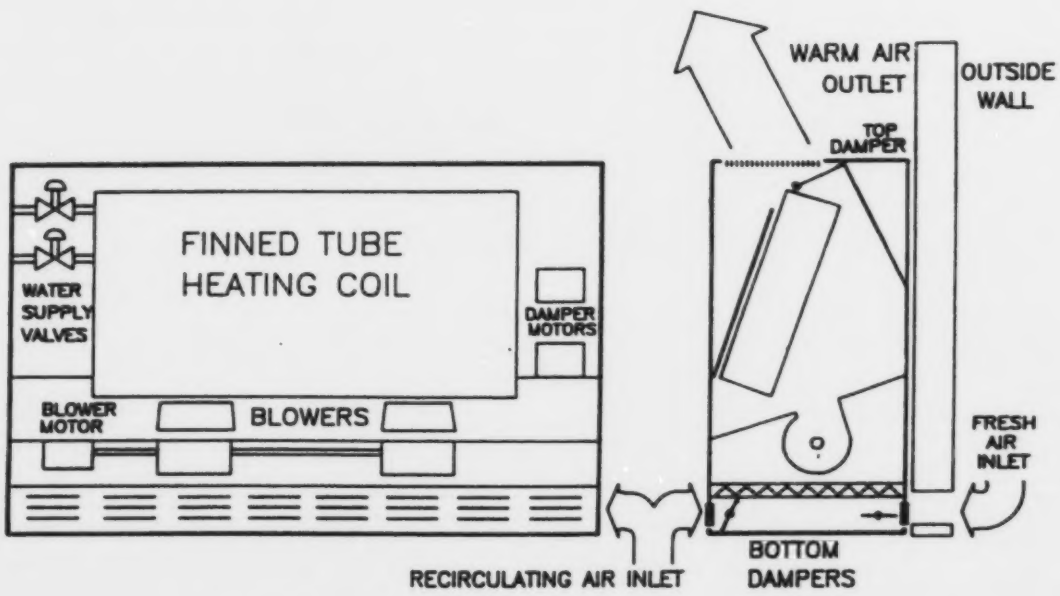
A schematic of the units used in this school is shown in Figure 9. A fixed flow of warm water is always passing through the finned tube coil. The unit is programmed to operate when the room is "occupied" (a function of the light switch for the room). Two damper motors control the flow of air. The bottom motor positions inlet dampers to supply a blend of recirculating and fresh air to the water coil. The top motor moves a damper which diverts air through or around the water coil, returning either heated or non-heated air to the classroom.

Problems occur in cold weather. When the unit ventilator satisfies the demand for heat, the thermostat directs the top damper to close. Fresh air is still drawn through the unit, but now it diverts around the water coil, and blows straight into the classroom. Teaching staff have reported snow blowing into the room through the unit! Staff also complain about the amount of blower noise generated, which means that the units are undersized for the amount of air they are expected to move, or perhaps the blower speeds are too high.

Complaints of draft are further aggravated by the provision of a single return duct in each classroom. This causes a plume of air to cross the room from the unit ventilator on the outside wall to the return duct at the inside wall, instead of being dispersed. These problems are compounded by the lack of a manual access to the thermostat, leaving the teaching staff frustrated about the inability to control the perceived noise, draft and temperature of their classroom.

With respect to the operation of the ventilation system, there are still some unanswered questions concerning the sizing of the ground coil and the contribution of the heat recovery unit.

The ground coil was sized to supply 75% of the peak heating demand for the school. The remaining demand was to be supplied by the electric back-up heaters, with a further contribution from the heat recovered in the exhaust air discharge. Because the electric back-up heaters never operate, temperatures fall so low in the school during cold weather that the recovery unit is shut down to prevent fresh air infiltration. As a result the ground loop must supply 100% of the demand. The heat pumps run longer, lowering the ground temperatures. This reduces heat pump efficiency, and the whole system suffers. It seems that during peak periods, and without back-up heaters, the system can either fully heat the school or fully ventilate the school, but not do both at the same time.



HEATING/COOLING UNIT FOR THE CLASSROOMS

Figure 9

Conclusions

1) Based on energy data that has been acquired for one complete year the ground-source heat pump has reduced space heating energy costs by over 60% compared to electric resistance heat. The electrical demand saving was measured to be 80 kW, a reduction in the overall building electric demand of 33%.

   From the observation of this building, it can be concluded that the use of ground source heat pumps can contribute greatly to a reduction in peak demand for power, and can reduce the overall consumption of energy for institutional buildings in general.

2) Operation of the ventilation system is critical to the successful design of an energy efficient school. Owners may be satisfied with reduced operating costs, but if occupants are not comfortable, their complaints will hinder the widespread use of any new technology.

3) Thorough commissioning is required if the building is expected to operate according to design. A qualified agent of the owner should always check the completion of all contracted and subcontracted work.

Approved by:

for A.F. Baljet
Manager
Electrical Research Department

Submitted:

F.J. Lenarduzzi
Utilization Engineer
Utilization Section

D. Vellekoop
Technologist
Utilization Section

Reviewed by:

D.J. Young
Unit Head - Thermal System
Utilization Section

FJL/DV:djb